Chapter 9. San Diego Regional Survey Macrobenthic Communities

INTRODUCTION

Macrobenthic invertebrates are an important component of the marine ecosystem throughout the entire Southern California Bight (SCB). Because of this and their proven ability to serve as reliable indicators of pollution or other stressors, benthic macrofauna have been sampled extensively over the last several decades to assess environmental impacts around SCB wastewater outfalls and other point sources at small spatial scales (e.g., Stull et al. 1986, 1996; Swartz et al. 1986, Ferraro et al. 1994, Zmarzly et al. 1994, Diener and Fuller 1995, Diener et al., 1995, Stull 1995). Although such local assessments are ongoing, larger-scale regional assessments have become an increasingly important tool over the past 15 years for evaluating benthic community condition and overall sediment quality (e.g., Bergen et al. 1998, 2000; Hyland et al. 2003, Ranasinghe et al. 2003, 2007; U.S. EPA 2004).

The City of San Diego has conducted regional benthic monitoring surveys off the coast of San Diego since 1994 (see Chapter 1). The main objectives of these annual surveys are to: (1) describe benthic conditions of the large and diverse coastal region off San Diego; (2) characterize the ecological health of the marine benthos in the area; (3) gain a better understanding of regional variation in order to distinguish between areas impacted by anthropogenic or natural factors. These regional surveys are comprised of an array of stations selected each year using a probability-based, random stratified sampling design (e.g., see Bergen 1996, Stevens 1997, Stevens and Olsen 2004). The 1994, 1998, 2003, and 2008 surveys off San Diego were conducted as part of larger, multi-agency surveys of the entire SCB, which included the 1994 Southern California Bight Pilot Project (SCBPP) and subsequent Bight'98, Bight'03 and Bight'08 regional monitoring programs. Results of the 1994−2003 SCB surveys are available in Bergen et al. (1998, 2001) and Ranasinghe et al. (2003, 2007, 2010), while data for Bight'08 are not yet available. The same general sampling design was used to select 40 new stations per year along the continental shelf (depths <200 m) for each of the other surveys restricted to the San Diego region in 1995–1997 and 1999–2002. Beginning in 2005, however, an agreement was reached between the City, the San Diego Regional Water Quality Control Board, and the U.S. EPA to revisit the same sites sampled 10 years earlier (i.e., 1995–1997 and 1999) in order to facilitate comparisons of long-term changes in benthic conditions. Thus, 34 stations that were successfully sampled in 1999 were revisited in 2009 along with 6 new sites. These latter new stations were targeted for upper slope depths between 200−500 m to expand the survey into deeper waters.

This chapter presents analysis and interpretation of the macrobenthic invertebrate data collected during the 2009 regional "random array" survey of continental shelf and slope benthic habitats off San Diego. Included are descriptions and comparisons of the soft-bottom macrobenthic assemblages and analyses of benthic community structure for the region.

Materials and Methods

Collection and Processing of Samples

The July 2009 regional survey covered an area ranging from off La Jolla in northern San Diego County south to the U.S./Mexico border (Figure 9.1). This survey revisited the same 34 sites that were successfully sampled in 1999 (see City of San Diego 2000). Although 40 sites were initially selected for the 1999 survey, sampling was unsuccessful at 6 sites due to the presence of rocky reefs or substrates. In order to augment the sampling design in 2009, six new stations were added using the same selection method, thus bringing the sample size

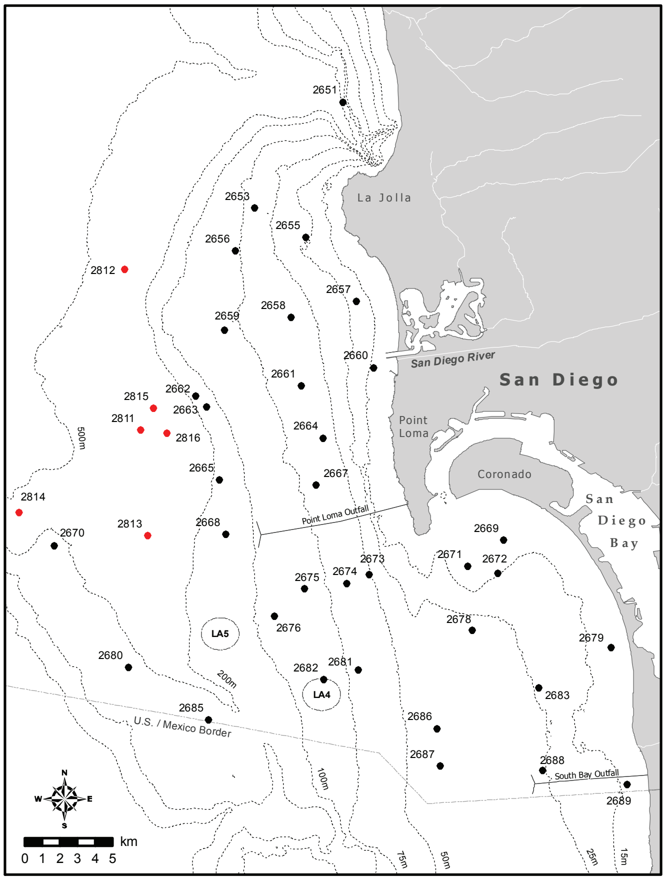

Figure 9.1
Regional benthic survey stations sampled during July 2009 as part of the South Bay Ocean Outfall Monitoring Program. Black circles represent shelf stations and red circles represent slope stations.

back up to 40 sites. These new sites were targeted for continental slope depths between 200−500 m to extend sampling to deeper habitats. Overall, the 2009 survey included stations ranging in depth from 11 to 413 m and spanning four distinct strata as characterized by the SCB regional monitoring programs (e.g., Ranasinghe et al. 2007).

Samples for benthic community analyses were collected using a double 0.1-m^2 Van Veen grab; one of the two grabs from each cast was used for macrofauna, while the other grab was used for sediment quality analysis (see Chapter 8). Criteria established by the EPA to ensure consistency of grab samples were followed with regard to sample disturbance and depth of penetration (U.S. EPA 1987). All samples were sieved aboard ship through a 1.0-mm mesh screen. Organisms retained on the screen were relaxed for 30 minutes in a magnesium sulfate solution and then fixed in buffered formalin. After a minimum of 72 hours, each sample was rinsed with fresh water and transferred to 70% ethanol. All animals were sorted from the sample debris into major taxonomic groups by a subcontractor, and then identified to species (or the lowest taxon possible) and enumerated by City of San Diego marine biologists.

Data Analyses

The following community structure parameters were calculated for each station per 0.1-m^2 grab: species richness (number of taxa), abundance (number of individuals), Shannon diversity index (H'), Pielou's evenness index (J'), Swartz dominance (Swartz et al. 1986, Ferraro et al. 1994), and the benthic response index (BRI; Smith et al. 2001). These data are summarized according to depth strata used in the Bight'98, Bight'03, and Bight'08 surveys: inner shelf (5–30 m), mid-shelf (30–120 m), outer shelf (120–200 m), and upper slope (200−500 m). The macrofauna data for 2009 were based on one benthic grab sample per station. While two grabs per station were sampled for macrofauna in the previous 1999 survey, only data from the first grab were reanalyzed here to facilitate comparison to 2009.

Multivariate analyses were performed using PRIMER software to examine spatio-temporal patterns in the overall similarity of benthic assemblages in the region (Clarke 1993, Warwick 1993, Clarke and Gorley 2006). These analyses included classification (cluster analysis) by hierarchical agglomerative clustering with group-average linking and ordination by non-metric multidimensional scaling (MDS). Macrofaunal abundance data were square-root transformed, and the Bray-Curtis measure of similarity was used as the basis for classification. Similarity profile analysis (SIMPROF) was used to confirm non-random structure of the resulting dendrograms (Clarke et al. 2008), while the 'similarity percentages' routine (SIMPER) was used to identify the species that typified each cluster group. Patterns in the distribution of the resultant assemblages were subsequently compared to several environmental variables by overlaying the physico-chemical data onto the MDS plots based on the macrofauna data (see Field et al. 1982, Clarke and Ainsworth 1993).

Results and Discussion

Community Parameters

Species richness

A total of 632 macrobenthic taxa (mostly species) were identified during the summer 2009 regional survey. Approximately 25% (n=161) of these were rare species or unidentifiable taxa (e.g., juveniles or damaged specimens) that occurred only once. Overall, species richness values (no. species/0.1-m^2 grab) ranged from 20 to 123 species per station at the four depth strata sampled in 2009 (Table 9.1). Such a wide variation in species richness is common for the region and is generally consistent with that observed during previous regional surveys including in 1999 (see Table 9.2). Species richness also varied between the major depth strata during both the 2009 and 1999 surveys (Figure 9.2A). For example, species richness was generally highest along the mid-shelf averaging between 80–93 species/grab during these two years, followed next by averages of 72–75 species/grab along the outer shelf and 60–64 species/grab along the inner shelf. In contrast, considerably fewer species (i.e., mean=34/grab) occurred at the deeper upper shelf sites that were first sampled in 2009.

Macrofaunal abundance

Macrofaunal abundance at shelf depths ranged from 100 to 630 animals per 0.1-m^2 sample in 2009 compared to 87–1166 individuals per grab in 1999 (Table 9.1, 9.2). The greatest number of animals in 2009 occurred at station 2660 located in shallow waters near the mouth of Mission Bay. Four other sites (i.e., stations 2671, 2678, 2680 and 2686) had abundance values greater than 440 individuals per grab, while the remainder of sites all had less than 400 animals per grab (Table 9.1). Abundance appeared to decrease slightly with depth across the shelf in 2009, averaging about 320 animals/grab along the inner shelf, 298 animals/grab along the mid-shelf, and 236 animals/grab along the outer shelf (see Figure 9.2B). In contrast, abundance values in 1999 were considerably higher at the mid-shelf stations (~415 animals/grab) than along either the inner or outer shelf (i.e., 304–305 animals/grab). Although the cause of this apparent difference is unknown, the pattern of higher abundances along the mid-shelf is more typical for the region. Finally, macrofaunal abundance along the upper slope during the 2009 survey averaged at least two-thirds fewer animals per sample (i.e., 84/0.1 m^2) than abundances at shelf depths during either 1999 or 2009 (Figure 9.2B).

Diversity and evenness

Diversity index (H') values ranged from 1.7 to 4.4 during 2009 (Table 9.1). Although most of the stations had H' values between 3.0–4.0, the five stations with the highest diversity (i.e., H'≥4.0) occurred predominantly along the mid-shelf (Table 9.1). The lowest H' value occurred at station 2671, a shallow-water station located near the mouth of San Diego Bay. Overall, diversity was similar to that observed in 1999 when values ranged from 1.9 to 4.3 (see Table 9.2, Figure 9.2C). Evenness (J') compliments diversity, with higher J' values (on a scale of 0–1) indicating that species are more evenly distributed, and that an assemblage is not dominated by a few highly abundant species. During 2009, J' values averaged between 0.46–0.94 (Table 9.1), with spatial patterns similar to those seen for diversity during both 1999 and 2009 (e.g., Figure 9.2D).

Dominance

Dominance was expressed as the Swartz dominance index, which is calculated as the minimum number of taxa whose combined abundance accounts for 75% of the individuals in a sample. Therefore, lower index values reflect fewer species and indicate higher numerical dominance. Values at the regional shelf stations ranged between 3–55 taxa per station during 2009 and 3–43 taxa per station in 1999, while values at the six deeper upper slope sites in 2009 ranged between 7–28 species (Table 9.1, 9.2). The pattern of dominance across

Table 9.1

Benthic community parameters calculated per 0.1-m^2 grab at regional stations sampled during 2009. SR = species richness; Abun = abundance; H' = Shannon diversity index; J' = evenness; Dom = Swartz dominance; BRI = benthic response index; na = not applicable; $n = 1$.

	Station	Depth (m)	SR	Abun	H'	J'	Dom	BRI
Inner Shelf	2655	26	53	349	3.1	0.77	11	17
	2657	21	73	281	3.7	0.87	26	20
	2660	13	61	630	2.5	0.62	7	4
	2669	11	55	264	3.1	0.78	15	9
	2671	13	45	451	1.7	0.46	3	10
	2672	15	52	156	3.5	0.88	18	18
	2678	29	104	442	3.8	0.81	31	26
	2679	13	45	349	2.6	0.68	7	21
	2683	24	69	272	3.4	0.79	19	18
	2688	26	58	166	3.5	0.85	22	25
	2689	14	40	160	3.2	0.87	14	18
Mid-shelf	2653	59	123	345	4.4	0.92	55	6
	2656	78	53	199	2.8	0.70	15	8
	2658	60	80	291	3.6	0.83	26	7
	2659	83	71	321	3.0	0.71	15	7
	2661	64	84	332	3.6	0.80	24	10
	2664	60	60	209	3.0	0.73	18	13
	2667	70	70	226	3.3	0.79	23	15
	2673	51	107	340	4.0	0.86	39	16
	2674	66	75	382	3.1	0.72	16	14
	2675	86	65	254	2.9	0.68	16	3
	2676	95	107	344	4.1	0.87	40	8
	2681	67	91	255	4.0	0.89	41	13
	2682	84	61	225	3.3	0.80	21	4
	2686	43	88	462	3.4	0.75	18	10
	2687	43	66	279	3.5	0.84	21	7
Outer Shelf	2651	163	82	316	3.7	0.85	27	20
	2662	147	71	237	3.8	0.90	29	16
	2663	128	87	247	3.8	0.86	37	13
	2665	177	42	100	3.5	0.94	21	23
	2668	151	62	137	3.8	0.91	29	11
	2670	169	54	147	3.2	0.80	19	7
	2680	138	109	447	4.0	0.84	30	6
	2685	122	72	258	3.7	0.86	25	10
Upper Slope	2811	404	20	54	2.3	0.78	7	na
	2812	357	27	87	2.7	0.83	11	na
	2813	257	56	112	3.7	0.92	28	20
	2814	413	29	62	3.1	0.92	14	na
	2815	349	34	106	3.0	0.84	12	na
	2816	335	35	85	3.0	0.86	14	na

Table 9.2

Benthic community parameters calculated per 0.1-m^2 grab at regional stations sampled during 1999. SR = species richness; Abun = abundance; H' = shannon diversity index; J' = evenness; Dom = Swartz dominance; BRI = benthic response index; $n = 1$.

	Station	Depth (m)	SR	Abun	H'	J'	Dom	BRI
Inner Shelf	2655	26	75	182	3.9	0.89	32	16
	2657	21	106	390	3.8	0.81	34	14
	2660	13	47	152	3.1	0.80	13	9
	2669	11	31	251	2.2	0.63	5	-1
	2671	13	60	637	2.3	0.56	7	9
	2672	15	34	356	1.9	0.53	3	1
	2678	29	107	395	4.1	0.89	37	23
	2679	13	43	211	3.1	0.82	13	17
	2683	24	81	406	3.6	0.81	21	14
	2688	26	85	229	3.9	0.88	35	22
	2689	14	33	141	2.9	0.84	10	14
Mid-shelf	2653	59	189	1166	4.2	0.81	42	3
	2656	78	80	473	3.1	0.72	13	2
	2658	60	88	313	3.5	0.79	23	11
	2659	83	65	294	2.8	0.66	10	-2
	2661	64	58	236	3.2	0.79	16	10
	2664	60	81	330	3.5	0.79	21	13
	2667	70	75	380	3.2	0.73	15	13
	2673	51	134	534	4.3	0.87	43	18
	2674	66	94	402	3.2	0.71	18	13
	2675	86	76	444	3.0	0.68	12	3
	2676	95	130	489	4.2	0.86	38	3
	2681	67	106	326	4.0	0.87	37	6
	2682	84	83	315	3.6	0.81	23	4
	2686	43	72	319	3.2	0.74	16	6
	2687	43	66	200	3.5	0.84	23	8
Outer Shelf	2651	163	60	371	2.4	0.59	6	21
	2662	147	75	421	3.5	0.82	22	10
	2663	128	133	619	4.1	0.83	34	4
	2665	177	41	141	3.0	0.81	13	8
	2668	151	68	278	3.4	0.80	20	8
	2670	169	57	157	3.5	0.86	23	-4
	2680	138	46	87	3.6	0.94	25	4
	2685	122	116	361	4.2	0.88	40	1

depth strata was generally similar between the 2009 and 1999 regional surveys (Figure 9.2E). For example, dominance was notably higher (i.e., lower index values) along the inner shelf (mean = 16–19 taxa) than at either the mid- or outer shelf stations (mean = 23–27 taxa) at these times. Average dominance at the upper slope stations in 2009 was similar to that seen along the inner shelf (i.e., mean = 14 taxa). As expected, dominance values also appeared to track diversity. During 2009 for example (see Table 9.1), the three sites with the lowest dominance (i.e., stations 2653, 2681 and 2676; index values ≥ 40) all had high H' values (i.e., ≥ 4.0), while the few stations with dominance index values < 10 (stations 2660, 2671, 2679 and 2811) had relatively lower H' values of 1.7–2.6.

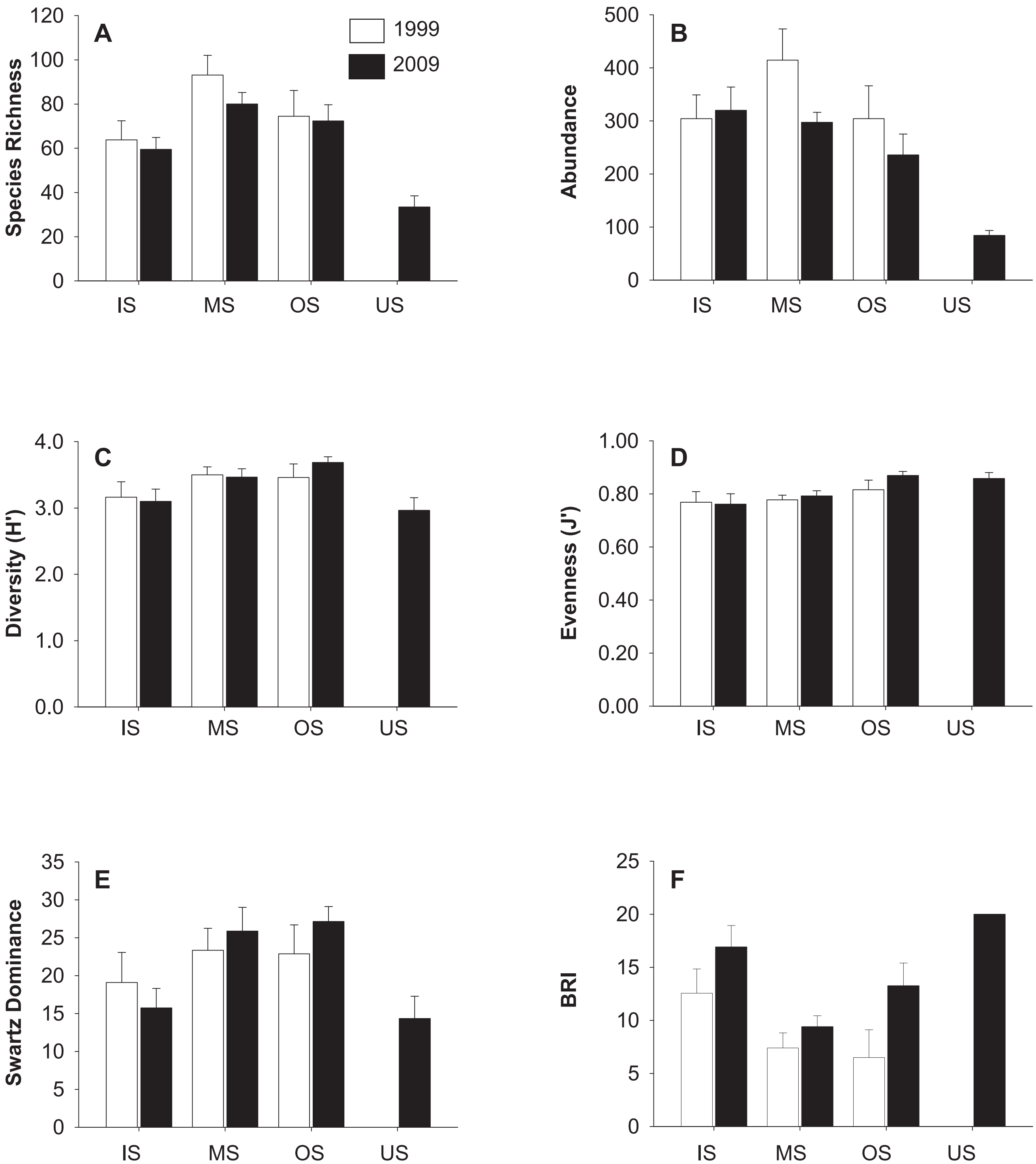

Figure 9.2

Comparison of benthic community structure metrics for the 2009 and 1999 regional surveys off San Diego (see text for details). Data are expressed for each depth stratum as means + one standard error (per 0.1 m^2) except for BRI on the upper slope where $n = 1$. IS = inner shelf (5–30 m; $n = 11$); MS = mid-shelf (30–120 m; $n = 15$); OS = outer shelf (120–200 m; $n = 8$); US = upper slope (200–500 m; $n = 6$ for 2009 only).

Benthic Response Index (BRI)

The benthic response index (BRI) is a useful tool for evaluating environmental conditions in soft-bottom benthic habitats off southern California that was originally calibrated for depths from 5 to 324 m (Smith et al. 2001). Index values below 25 (on a scale of 100) are considered indicative of reference conditions, while those between 25 and 34 represent a minor or marginal deviation that should be confirmed by additional sampling. Higher BRI values > 34 are considered to represent progressive levels of impact, including losses in biodiversity or community function, and ultimately defaunation. BRI values ranged from 3 to 26 at the regional shelf stations in 2009 (Table 9.1). Thus, BRI values throughout the San Diego region were mostly indicative of reference conditions during the year. Only two stations (2688 and 2678) had slightly higher BRI values of 25−26, and these occurred at shallow depths along the inner shelf where the BRI can be less reliable (Ranasinghe et al. 2010). These same two stations also had the highest BRI values in 1999, although no station sampled during that survey had a BRI ≥25 (see Table 9.2). Average BRI values also varied between the major depth strata, although all remained characteristic of reference conditions as discussed above (see Figure 9.2F). For example, during the 1999 and 2009 surveys, respectively, BRI values averaged 13 and 17 along the inner shelf, 7 and 9 at the mid-shelf sites, and 7 and 13 along the outer shelf. Although a BRI of 20 is reported herein for station 2813 located at 257 m on the upper slope, the reliability of this value is questionable as there has been only limited calibration of the index for depths between 200–324 m (Ranasinghe et al. 2010). Additionally, index values were not calculated for the five deeper slope stations since there has been no calibration of the BRI for sites greater than 324 m depth.

Dominant Taxa

Macrofaunal communities in the San Diego region were generally dominated by annelids (i.e., mostly polychaete worms) in 2009 (Table 9.3), although proportions of the various taxa varied between the four depth strata (Figure 9.3). Polychaetes were the most diverse of the major taxa over all strata, accounting for 51% of all species collected. Molluscs and arthropods (mostly crustaceans) were the next two most diverse taxa, accounting for 19% and 18% of species, respectively. Echinoderms comprised 6% of all taxa, while all other phyla combined (e.g., Chordata, Cnidaria, Nematoda, Nemertea, Phoronida, Platyhelminthes, Sipuncula) accounted for the remaining 6%. A few patterns were apparent in the proportions of the major taxa comprising the different assemblages (see Figure 9.3A). For example, the percentage of polychaetes increased across the continental shelf from 47% along the inner shelf, to 52% along the mid-shelf, to 61% along the outer shelf. Echinoderms also increased slightly across these depths, while the proportions of crustaceans, molluscs and the other phyla appeared to decrease. The greatest difference occurred along the upper slope where the percentage of molluscs increased sharply to comprise about 32% of all taxa. Echinoderms also accounted for a larger proportion of species at upper slope sites than on the shelf, while the proportions of polychaetes and crustaceans decreased compared to the outer shelf.

Polychaetes were also the most numerous invertebrates overall, accounting for 51% of the total abundance. Molluscs accounted for 21% of the animals, crustaceans 12%, echinoderms 13%, and the remaining

Table 9.3
The percent composition of species and abundance by phyla for regional stations sampled during 2009. Data are expressed as means (range) for all stations combined; $n=40$.

Phyla	Species (%)	Abundance (%)
Annelida (Polychaeta)	51 (31–73)	51 (19–85)
Arthropoda (Crustacea)	18 (0–33)	12 (0–32)
Mollusca	19 (7–41)	21 (3–70)
Echinodermata	6 (0–14)	13 (0–48)
Other Phyla	6 (0–15)	3 (0–22)

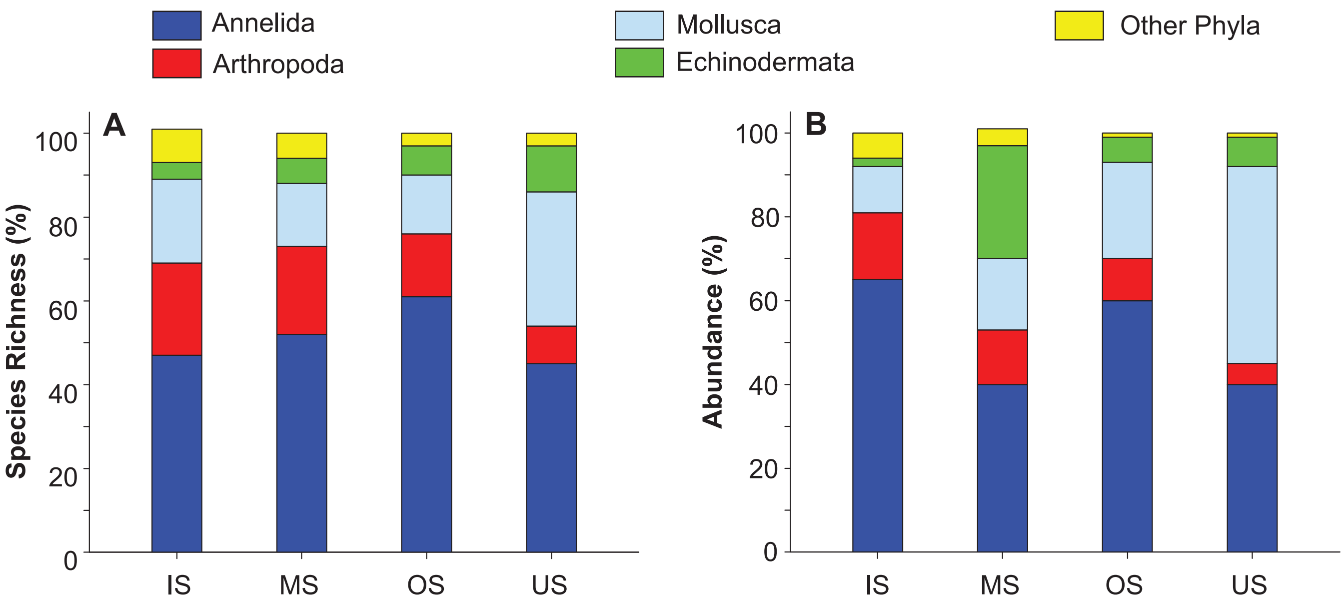

Figure 9.3

Comparison of percent composition of species and abundance by major phyla for each depth stratum sampled at the regional stations during 2009. IS = inner shelf (5–30 m; *n* = 11); MS = mid-shelf (30–120 m; *n* = 15); OS = outer shelf (120–200 m; *n* = 8); US = upper slope (200–500 m; *n* = 6).

phyla 3%. Abundance patterns also varied between strata (see Figure 9.3B). For example, the proportion of polychaetes was lower at the mid-shelf and upper slope stations (i.e., 40% each) than along either the outer or inner shelf (i.e., 60−65%). The lower proportion of polychaetes along the mid-shelf and upper slope corresponded to considerably higher numbers of ophiuroids at mid-shelf depths (i.e., 27%) and molluscs at the deeper slopes sites (i.e., 47%).

As expected, the numerically dominant species characteristic of the benthic assemblages off San Diego also varied between strata (see Table 9.4). For example, the top 10 most abundant species along the inner shelf included eight polychaetes, one cumacean, and one anthozoan. Of these, the oweniid polychaete *Owenia collaris*, and the spionid polychaete *Spiophanes norrisi*, were clearly dominant with averages of about 65 and 21 individuals per 0.1-m^2 grab, respectively. The remaining inner shelf species all averaged < 11 animals/grab. Additionally, *S. norrisi* was the most widely distributed of these species occurring at all 11 of the inner shelf sites. In contrast, *O. collaris* had a more restricted distribution occurring at only six sites. The top 10 dominants along the mid-shelf included four ophiuroid taxa, four polychaetes, and two bivalves. The brittle star *Amphiodia urtica* was by far the most common invertebrate at these depths, averaging about 58 animals per grab and occurring at 87% of the sites. However, it is likely that two of the other “dominant” ophiuroid taxa reported here (i.e., *Amphiodia* sp and Amphiuridae) represent mostly juvenile *A. urtica* that could not be identified to species. Thus, if total *A. urtica* abundance is adjusted to include putative *A. urtica* juveniles, then the estimated density would increase to about 69 brittle stars per grab. The bivalve *Axinopsida serricata* was the next most abundant species at the mid-shelf stations, averaging about 18 animals per grab, while all other species at these depths averaged < 10 animals/grab. The top 10 species along the outer shelf included six polychaetes, three bivalves, and one gastropod. However, densities were relatively low with neither of the two most abundant species on the outer shelf, the bivalves *Tellina carpenteri* and *A. serricata*, exceeding mean densities of 13 animals/grab. The 10 most abundant species at upper slope depths included five bivalves and two scaphopods, as well as three polychaete taxa. The bivalves *Nuculana conceptionis* and *Macoma carlottensis* were the two most abundant species on the upper slope, each averaging about 9 animals/grab.

Table 9.4

The 10 most abundant macroinvertebrates collected at the regional benthic stations sampled during 2009. AS = abundance/survey; PO = percent occurrence; AO = abundance/occurrence. Abundance values are expressed as mean number of individuals per 0.1-m^2 grab sample.

Strata	Species	Higher Taxa	AS	PO	AO
Inner Shelf	*Owenia collaris*	Annelida: Oweniidae	64.5	55	118.5
	Spiophanes norrisi	Annelida: Spionidae	20.7	100	20.7
	Zaolutus actius	Cnidaria: Anthozoa	10.2	36	27.9
	Monticellina siblina	Annelida: Cirratulidae	8.7	46	19.2
	Mooreonuphis nebulosa	Annelida: Onuphidae	6.9	18	38.4
	Mediomastus sp	Annelida: Capitellidae	6.6	91	7.5
	Polydora cirrosa	Annelida: Spionidae	6.6	27	24.6
	Diastylopsis tenuis	Arthropoda: Cumacea	6.6	55	12.3
	Spiophanes duplex	Annelida: Spionidae	6.6	82	8.1
	Spio maculata	Annelida: Spionidae	5.4	9	60.0
Mid-shelf	*Amphiodia urtica*	Echinodermata: Ophiuroidea	57.9	87	66.9
	Axinopsida serricata	Mollusca: Bivalvia	18.0	87	20.7
	Spiophanes norrisi	Annelida: Spionidae	9.9	20	49.8
	Amphiodia sp	Echinodermata: Ophiuroidea	7.5	80	9.3
	Spiophanes berkeleyorum	Annelida: Spionidae	6.3	80	7.8
	Ennucula tenuis	Mollusca: Bivalvia	5.4	73	7.5
	Euclymeninae sp A	Annelida: Maldanidae	4.5	87	5.1
	Mooreonuphis sp SD1	Annelida: Onuphidae	3.9	13	29.1
	Ophiuroconis bispinosa	Echinodermata: Ophiuroidea	3.6	67	5.4
	Amphiuridae	Echinodermata: Ophiuroidea	3.6	73	4.8
Outer Shelf	*Tellina carpenteri*	Mollusca: Bivalvia	12.9	88	14.7
	Axinopsida serricata	Mollusca: Bivalvia	11.4	75	15.3
	Aphelochaeta glandaria complex	Annelida: Cirratulidae	8.4	62	13.2
	Fauveliopsis sp SD1	Annelida: Fauveliopsidae	8.1	25	32.4
	Terebellides californica	Annelida: Trichobranchidae	8.1	50	15.9
	Micranellum crebricinctum	Mollusca: Gastropoda	6.6	38	17.4
	Monticellina siblina	Annelida: Cirratulidae	6.0	75	8.1
	Mediomastus sp	Annelida: Capitellidae	6.0	88	6.6
	Chaetozone sp	Annelida: Cirratulidae	5.7	38	15.3
	Parvilucina tenuisculpta	Mollusca: Bivalvia	5.4	100	5.4
Upper Slope	*Nuculana conceptionis*	Mollusca: Bivalvia	9.3	83	11.1
	Macoma carlottensis	Mollusca: Bivalvia	8.7	67	13.2
	Maldane sarsi	Annelida: Maldanidae	5.4	67	8.1
	Maldanidae	Annelida: Maldanidae	5.1	67	7.8
	Gadila tolmiei	Mollusca: Scaphopoda	2.4	100	2.4
	Compressidens stearnsii	Mollusca: Scaphopoda	2.4	67	3.9
	Ennucula tenuis	Mollusca: Bivalvia	2.1	83	2.4
	Spiophanes kimballi	Annelida: Spionidae	2.1	67	3.0
	Saxicavella pacifica	Mollusca: Bivalvia	2.1	17	12.0
	Tellina carpenteri	Mollusca: Bivalvia	1.8	33	5.4

Classification of Macrobenthic Assemblages

Classification and ordination analyses were used to discriminate between the major macrobenthic assemblages that occur off San Diego. Two separate analyses were conducted this year, the first which compared the macrofaunal abundance data collected during both 1999 and 2009 at the 34 continental shelf stations (i.e., $n = 68$ station/survey entities). The six deeper slope stations sampled in 2009 were excluded from this analysis. Most stations sampled in 2009 clustered with or closely to their 1999 counterparts (see Appendix H.1), thus suggesting that macrofaunal communities along the San Diego shelf remained generally similar during these two periods. Consequently, a more detailed assessment was performed restricted to just the stations sampled in 2009, including both shelf and slope sites (i.e., $n = 40$ stations). The results of this second analysis are described below.

Seven main habitat-related macrobenthic assemblages were identified in 2009 based on results of the ordination and cluster analyses (Figure 9.4). These assemblages, referred to herein as cluster groups A–G, varied in terms of the specific taxa (mostly species) present and the relative abundance of each taxon, and occurred at sites separated by different depths and/or sediment microhabitats (see Figure 9.5, 9.6). The SIMPROF procedure indicated statistically significant non-random structure among samples ($\pi = 7.92$, $p < 0.001$), and an MDS ordination supported the validity of the cluster groups (Figure 9.4B). SIMPER analysis was used to identify species that were characteristic, though not always the most abundant, of each assemblage. For example, the three most characteristic species identified by SIMPER for cluster groups B–G are indicated in Figure 9.4A; the exception to this is that the three most abundant species are listed for cluster group A, since this group is comprised of a single sample for which the SIMPER routine cannot be performed. A complete list of species comprising each cluster group and their relative abundances can be found in Appendix H.2.

Cluster group A represented a unique assemblage restricted to station 2655 sampled in relatively shallow water (26 m) off the southwest tip of La Jolla, which was associated with very coarse sediments. A total of 53 taxa and 349 individuals occurred in this single 0.1 m^2 grab sample. This inner shelf assemblage was characterized by several species of polychaetes that commonly occur in coarse benthic habitats, including the spionid *Spio maculata*, the lumbrinerid *Lumbrinerides platypygos*, the pisionid *Pisione* sp, and the phyllodocid *Hesionura coineaui difficilis*. Another species common in coarse sediments, the cephalochordate *Branchiostoma californiense*, was present as well. Sediments at this site were comprised almost entirely of sand and shell hash with 0% fines, and with a total organic carbon (TOC) content of 0.8% weight (% wt).

Cluster group B represented an assemblage from six inner shelf stations that ranged in depth from 11 to 14 m. The assemblage at these stations was typical of shallow-water sites in the region, and had an average of 50 taxa and 335 individuals per 0.1 m^2. Characteristic species included the oweniid polychaete *Owenia collaris*, and the spionids *Spiophanes norrisi* and *S. duplex*. Sediment composition at the sites within this group averaged 7% fines and 0.2% wt TOC.

Cluster group C represented an assemblage from six sites located at depths between 21 and 43 m. Species richness for this inner to shallow mid-shelf assemblage averaged 76 taxa, while abundance averaged 317 individuals per 0.1 m^2. Polychaetes were numerically dominant, with the spionids *Spiophanes norrisi* and S. *berkeleyorum*, as well as the maldanid Euclymeninae sp A, representing the three most characteristic species. Sediments at these sites were comprised mostly of coarse particles, including shell hash and red relict sand with an average of only 10% fines, along with an average TOC content of 0.2% wt.

Cluster group D represented the deepest assemblage sampled at five of the six sites located along the upper continental slope at depths between 335 and 413 m.

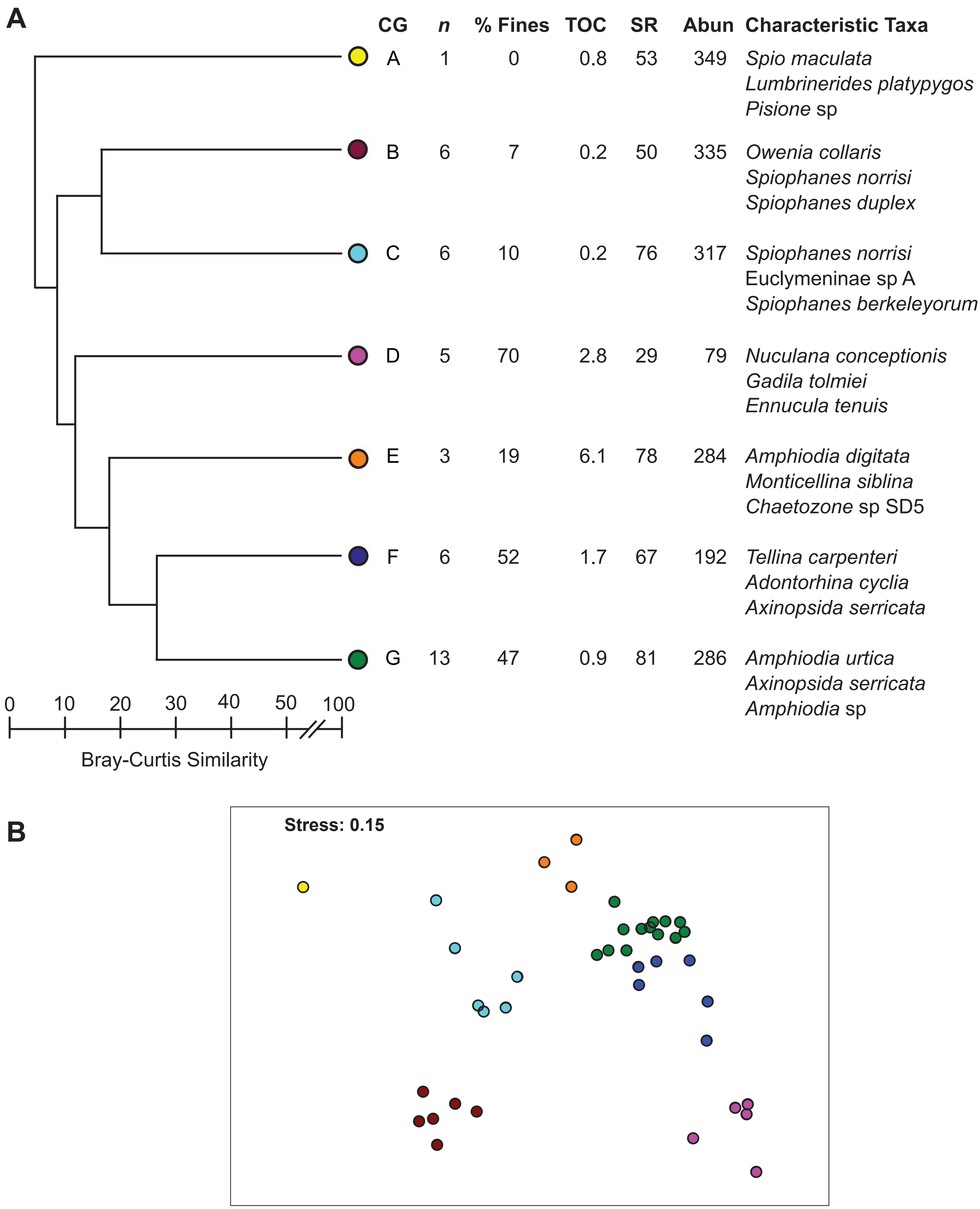

Figure 9.4

(A) Cluster results of the macrofaunal abundance data for the regional benthic stations sampled during summer 2009. Data for percent fines, total organic carbon (TOC), species richness (SR), and infaunal abundance (Abun) are expressed as mean values per 0.1-m^2 grab over all stations in each group. (B) MDS ordination based on square-root transformed macrofaunal abundance data for each station.

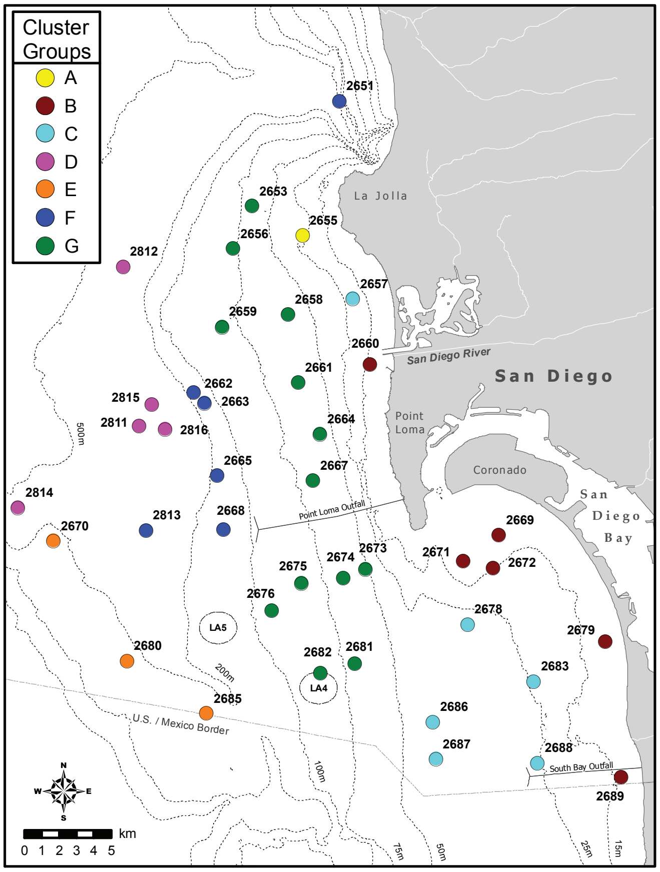

Figure 9.5
Spatial distribution of the 2009 regional macrobenthic assemblages delineated by ordination and classification analyses.

This assemblage averaged 29 taxa and 79 individuals per 0.1 m^2, the lowest values among all cluster groups. Molluscs were numerically dominant at these upper slope sites, with the three most characteristic species being the bivalves *Nuculana conceptionis* and *Ennucula tenuis*, and the scaphopod *Gadila tolmiei*. The sediments characteristic of these deep samples averaged considerably finer particles (i.e., 70% fines) compared to those in the other six groups (i.e., 0–52% fines), and had an average TOC value of 2.8% wt.

Cluster group E represented an assemblage from three stations located on the Coronado Bank at depths of 122–169 m. This outer shelf assemblage averaged 78 taxa and 284 individuals per 0.1 m^2. The characteristic species included the ophiuroid *Amphiodia digitata*, and the cirratulid polychaetes *Monticellina siblina* and *Chaetozone* sp SD5. The sediments characteristic of these samples were relatively coarse containing pea gravel, rock, shell hash and 19% fines. TOC content at these sites averaged of 6.1% wt, which was considerably higher than for any of the other groups.

Cluster group F represented an assemblage present at six sites, including five outer shelf stations at depths of 128–177 m, as well as the shallowest upper slope station at 257 m (i.e., station 2813). This assemblage averaged 67 taxa and 192 individuals per 0.1 m^2. The three most characteristic species were the bivalves *Tellina carpenteri*, *Adontorhina cyclia*, and *Axinopsida serricata*. Sediments at these sites averaged 52% fines and had an average TOC content of 1.7% wt.

Cluster group G represented an assemblage from most of the mid-shelf sites (n=13) that ranged in depth from 51 to 95 m. This group had the highest average species richness (81 species) and averaged 286 individuals per 0.1 m^2. Overall, this assemblage is typical of the ophiuroid dominated community that occurs along much of the mainland shelf off southern California (see Mikel et al. 2007, City of San Diego 2010). The taxa characteristic of this mid-shelf assemblage included the ophiuroid *Amphiodia urtica*, juvenile *Amphiodia*, and the bivalve *Axinopsida serricata*. The sediments associated with this group were mixed, averaging 47% fines, and with an average TOC concentration of 0.9% wt.

Summary and Conclusions

The summer 2009 regional benthic survey was different than the previous regional surveys off San Diego (see City of San Diego 1999−2003, 2006−2008) in that it included samples from deep waters along the upper continental slope (200−500 m) as well as shelf habitats <200 m depth. Although soft-bottom benthic invertebrate communities often exhibit considerable spatial and temporal variability (e.g., Morrisey et al. 1992a, 1992b; Otway 1995), the general distribution and types of macrobenthic assemblages along the San Diego shelf have shown little net change since the regional

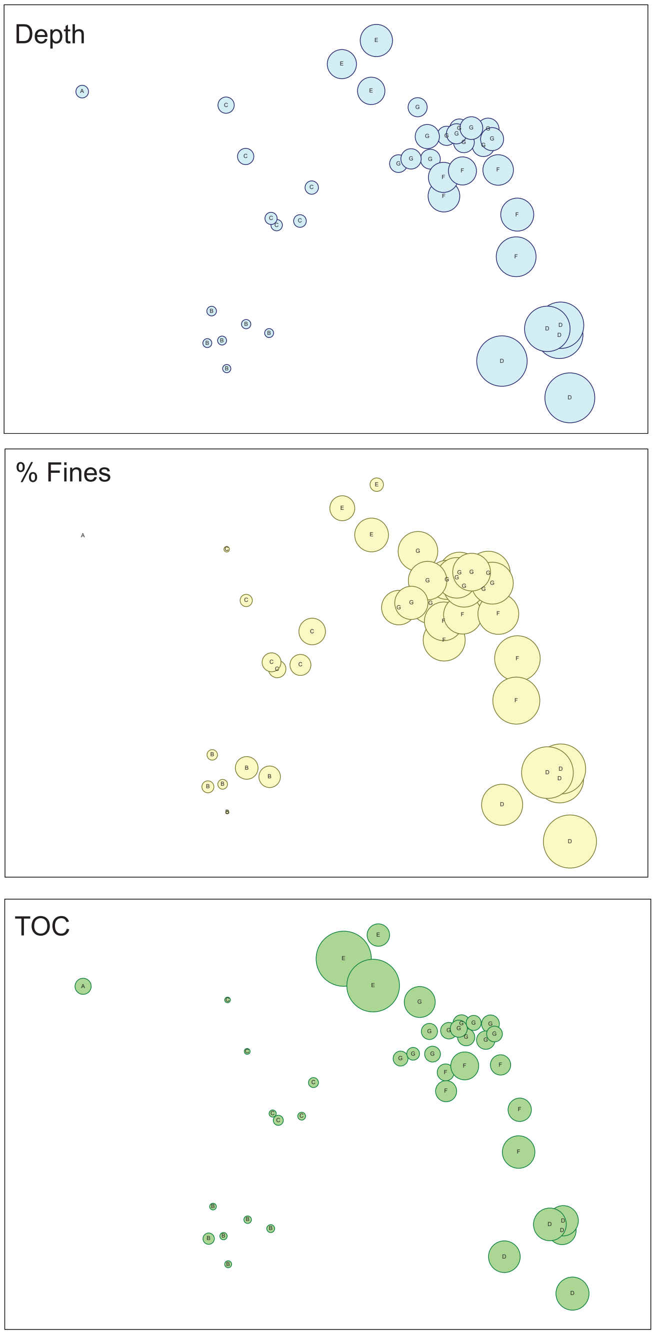

Figure 9.6

MDS ordination of macrofaunal abundance data for 2009 regional stations (see Figure 9.4), with superimposed circles representing station depth, and the amount of fine particles (% fines) and total organic carbon (TOC, % wt) in sediments. Circles vary in size according to the magnitude of each value.

surveys began. For example, the results of a cluster analysis of the same sites sampled in 1999 and 2009 showed that most stations clustered with or closely to their counterparts in both years. A more detailed comparison of the seven assemblage types described herein for 2009 with those reported for 1999 (see City of San Diego 2000) also indicated considerable similarity. Evaluation of differences in several important measures of benthic community structure (e.g., species richness, abundance, diversity, benthic response index) between the different depth strata over this time span was also indicative of long-term stability. Possible exceptions included disparities in species richness and abundance at mid-shelf depths, both of which were higher in 1999. It is unclear what may be the cause off these differences, although a major El Niño that occurred in 1998 could be responsible for an influx of typically more southern species into the region around that time. In contrast, it seems likely that the difference in abundances may reflect lower numbers than normal during 2009 as the pattern of higher abundances along the mid-shelf seen in 1999 is more typical for the SCB.

The SCB benthos has long been considered to be composed of "patchy" habitats, with the distribution of species and communities exhibiting considerable spatial variability. Results of the regional surveys off San Diego generally support this characterization. The 2009 benthic assemblages appeared to segregate primarily by habitat characteristics such as depth (i.e., strata) and sediment grain size, and were similar to those sampled in the past except for at the slope sites. About one-third of the benthos sampled off San Diego in 2009 was characterized by a mid-shelf, mixed sediment (i.e., 47% fines) assemblage dominated by the ophiuroid *Amphiodia urtica* (i.e., cluster group G). This assemblage corresponds to the *Amphiodia* "mega-community" described by Barnard and Ziesenhenne (1961), and is common in the Point Loma region off San Diego (e.g., City of San Diego 2010) as well as other parts of the southern California mainland shelf (e.g., Jones 1969, Fauchald and Jones 1979, Thompson et al. 1987, 1993; Zmarzly et al. 1994, Diener and Fuller 1995, and Bergen et al. 1998, 2000, 2001).

Several distinct nearshore assemblages were also present off San Diego that were generally similar to those found in shallow, sandy sediment habitats in the SCB (see Barnard 1963, Jones 1969, Thompson et al. 1987, 1992; ES Engineering

Science 1988, Mikel et al. 2007). For example, the group B and C assemblages occurred at inner to shallow mid-shelf sites (11−43 m) characterized by coarse sediments averaging between 7−10% fines. Polychaetes such as *Owenia collaris* and *Spiophanes norrisi* were numerically dominant in these two assemblages. The single site that constituted the third shallow assemblage (group A) was characterized by even coarser sediments with no fines. This assemblage was dominated by the polychaetes *Spio maculata* and *Lumbrinerides platypygos*, and also contained several other species associated with very coarse sediments.

Two different assemblages were present along the outer shelf at depths between 122−177 m and at one deeper station (257 m) located near the top of the upper slope. The group E assemblage occurred along the Coronado Bank where sediments were relatively coarse (~19% fines). Species characteristic of this assemblage included the brittle star *Amphiodia digitata* and two cirratulids (i.e., *Monticellina siblina* and *Chaetozone* sp SD5). In contrast, the group F assemblage was characterized by several species of bivalve molluscs (e.g., *Tellina carpenteri*, *Adontorhina cylcia*, and *Axinopsida serricata*), and occurred in mixed sediments averaging 50% fines.

As expected, the upper slope represents a unique habitat off San Diego compared to shallower areas, with the macrofauna from the five deepest stations (335−413 m) clustering together as group D. Sediments at these sites had the highest percentage of fine particles averaging 70% fines. These sites were distinguished by considerably fewer species and lower abundances than along the shelf, while characteristic species included various species of molluscs such as the bivalves *Nuculana conceptionis* and *Ennucula tenuis*, and the scaphopod *Gadila tolmiei*.

Although benthic communities off San Diego vary across depth and sediment gradients, there was no evidence of disturbance during the 2009 regional survey that could be attributed to wastewater discharges, disposal sites or other point sources. Overall, benthic macrofauna appear to be in good condition throughout the region, with 94% of the sites surveyed in 2009 being in reference condition and the remaining 6% deviating only marginally based on assessments using the benthic response index (BRI). This is not unexpected as Ranasinghe et al. (2010) recently reported that 98% of the entire SCB was in good condition based on assessment data gathered during the 1994−2003 bight-wide surveys.

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